MODIS Snow and Ice Project
Semi-Annual Report (January - June 1995)
Submitted by: D.K. Hall/974

Summary

Research progress has been made in several areas during the last 6 months, and the April aircraft mission in Alaska has been successfully completed. Five presentations were made and 2 papers have been accepted for publication; 1 abstract was published. Plans for the MODIS snow/ice workshop to be held in September are being finalized.

I. Research Progress

Optical/Passive Microwave data comparison of snow-cover data (V. Salomonson, D. Hall, J. Chien and G. Riggs). We obtained several data sets of the U.S. and Canada during the winter, and registered SMMR or SSMI data to the AVHRR data. This was done in order to map the data to a common grid so that comparisons between data sets will be meaningful. We have collaborated with the NSIDC at the University of Colorado in order to locate and grid the AVHRR and SSMI data. A sample time series of data sets was prepared. The sample shows that gridding the AVHRR Pathfinder and SSMI data to NSIDCís EASE-Grid can be done successfully. The drawback to doing that in an automated way is that the AVHRR sensor does not have the proper channels for snow/cloud separation and thus is not suitable for mapping snow without human intervention.

Gridded AVHRR data from 15 May 1994 were obtained of Alaska from the Alaska SAR Facility in Fairbanks. These data were mosaicked and registered with gridded SSMI data. An excellent comparison was made which showed a distinct snowline on the North Slope of Alaska on both the AVHRR and SSMI data. Unfortunately, snow in the Alaska Range was not mapped by the SSMI snow-mapping algorithm because of melting in the Alaska Range in mid-May. The wet snow had a microwave brightness temperature that was similar to the surrounding terrain and was thus not mapped as snow.

A paper was prepared on this general topic and presented at the Combined Optical-Microwave Earth and Atmosphere Sensing Conference (Co-Meas) which was held in April 1995. See section IV and Appendix I.

Snow and sea ice algorithm development (G. Riggs). Development of the MODIS snow and sea ice algorithms (daily and weekly) has been progressing. Betathern BOREAS test site in Canada in February of 1994. The only 2 good MAS scenes were registered to the TM scene, which was acquired 2 days after the MAS data were acquired. Results showed that more snow was mapped in coniferous forests than in deciduous forests. The forest cover was determined from a TM-derived map by Forrest Hall/code 923. The dense deciduous stands precluded mapping snow underneath, while the coniferous stands had some snow in the canopy which was mapped. A paper on this topic was prepared and presented at the Eastern Snow Conference held in June in Toronto, Canada. See section IV and Appendix II.

Passive-Microwave Algorithm Development (J. Foster). Jim Foster, in connection with his Ph.D. research, has refined passive-microwave algorithms to determine global snow depth. The matter of the shape of snow grains and how shape affects microwave emission and scattering has only been dealt with in a cursory manner. Current algorithms assume that all the grains are spherical and do not account for irregularly-shaped snow grains. Even when depth hoar crystals have been modeled, spherical grains are used with a diameter approaching the longest length scale of the depth hoar crystal. The myriad of possible shapes and sizes encountered in a snowpack makes modeling the radiative transfer an especially arduous task. The microwave algorithm that we have developed and refined, mimics the snowpack as a single layer having spherical snow grains of 0.3 mm radiuus for all land areas, except the continental interiors (boreal forest areas) where larger grain sizes are prescribed. Additionally, in boreal forest areas the effect of the vegetation on the microwave signal is considered by using a forest cover parameter derived from an albedo index. Fosterís Ph.D. was successfully completed in June 1995.

Spectral-mixture modeling (A. Nolin). Dr. Anne Nolin, under contract to NASA for this project, has run a spectral mixture model on the 14 March 1991 TM image of Glacier National Park. This is a scene that we have previously classified using SNOMAP. Her results show that SNOMAP mapped about 4.2 percent more snow than was mapped by the spectral mixture model technique. It is believed that the SNOMAP results are more accurate because simultaneous ground truth showed that there was a complete snow cover on 14 March. (See section IV and Appendix III.)

Use of Spectral Mixture Analysis for Mapping Snow Covered Area and Sea Ice

I. Introduction:

This research assesses the efficacy of using spectral mixture analysis (SMA) as a tool for global mapping of snow-covered area at sub-pixel spatial resolution.

The spatial distribution of snowcover is a parameter required for climate models, where surface albedo is used as a lower boundary condition, and for snowmelt/runoff models, in which snow-covered area is needed for spatially-distributed melt calculations. One of the fundamental difficulties in producing estimates of snow-covered area using remote sensing techniques has been distinguishing snow from other surface covers in a scene. A second major difficulty lies with the mixed pixel effect that arises from the spectral input of different materials (snow, rock,

vegetation, etc.) in the sensor field-of-view. Binary classifications from remote sensing data categorize pixels as either completely snow-covered or completely non-snow-covered. This simplistic approach can introduce large errors in the estimation of snow covered area, particularly in regions where and at times when snow cover is patchy and discontinuous.
One distinct advantage of the SMA technique is that it allows one to estimate the fractional snowcover in a pixel. In addition, the fit of the model to the data can be tested and, unlike most binary classification methods, an error estimate is provided.

SMA uses a linear mixing model in which the sensor response for an image pixel is expressed as a linear combination of the fractional quantity of each component present in the pixel. Thus, each pixel spectrum holds information about both the spectral signature and the fractional abundance of a component. Figure XX depicts the hypothetical spectrum of a pixel containing 60% snow and 40% vegetation. In a multispectral image each pixel can be modeled as a linear combination of components identified for that image. Such image components are termed "endmembers" and they are thought to be representative of a finite set of spectrally-unique ingredients in the image. For an atmospherically-corrected, multispectral reflectance image, a linear mixture of the endmembers is calculated using
the relationship:

$$R_c = \sum_{i=1}^{N} F_i R_{(i,c)} + E_c$$

where, R_c is apparent surface reflectance
F_i is the fraction of endmember, i
N is the number of spectral endmembers
and, E_c is the error for channel c of the fit of the model to the data.

To solve for the F_i's the model performs a
least-squares fit to the spectrum of each pixel.
The fit of the linear mixture model to the spectral data in each pixel is measured by the error term, E_c.
Equation 2 calculates the average
root mean-squared (RMS) error by squaring and summing
E_c over M number of sensor channels to show the model fit.

$$RMS = \left[M^{-1} \sum_{c=1}^{M} E_c^2 \right]^{1/2}$$

Spectral endmembers are chosen from each image and, though the same category of endmember may be the same for many images (eg. rock, snow, vegetation), their spectral characterization is expected to differ from one image to another because of changes in solar illumination, differences in rock, vegetation or snow-type and so on. After atmospheric correction of the image data, using the 5S model, a principal components analysis (PCA) is performed on the multispectral data. PC images are examined and the locations of pixels having the highest value in each PC image are marked. These marked pixels are then located in the reflectance images and the reflectance spectra of these pixels are used as the endmember spectra. The spectral unmixing model is iteratively run (each time solving for the fraction of each endmember in each pixel) with successively fewer endmembers until both the overall RMS error is minimized and the fraction of each endmember lies between the values of 0 and 1.

II. Approach:

A. Remote sensing data used include:

TM image of Glacier National Park, Montana (March 14, 1995)
AVIRIS image of Mammoth Mountain, California (January 11, 1993)
Mapping Alpine Snow Cover:

B. Alpine Snow Cover Mapping:

In this research, multi-spectral remotely sensed data from both Landsat Thematic Mapper (TM) and Airborne Visible/Near-Infrared Imaging Spectrometer (AVIRIS) of sensors were used as proxy data for MODIS. TM data represent the data having the closest spectral match to the MODIS data and these data have already been used to test both a SMA-based and NDSI-based snow mapping algorithm so it is appropriate to use these TM data for comparison of the two techniques. Landsat TM has a 30 m spatial resolution while MODIS has 250 m to 1 km spatial resolution.

AVIRIS has a spatial resolution of 20 meter, a spectral range from 400-2450 nm and a nominal spectral resolution of 10 nm.
It is flown in a NASA ER-2 aircraft at an altitude of 20\km and has a swath width of 12 km. To better characterize the full number of spectral bands that may be used for snow mapping, AVIRIS channels were convolved to MODIS spectral resolution (based on current band characteristics) and results of each algorithm were compared on a spectral basis.

Both regions are rugged, mountainous terrain with snow, rock and alpine and subalpine vegetation present. Alpine snow cover in both the Mammoth Mountain and Glacier National Park images were mapped using the SMA method. The AVIRIS image is of Mammoth Mountain on January 11, 1993, acquired shortly following a snowfall of about 10-20 cm. The snowpack at the time was approximately 2-3 m deep over most of the mountain. The Glacier National Park TM image, acquired on March 14, 1991, also shows abundant fresh snow.

Because of disk space and computational limitations, subscenes of each image were used. The AVIRIS image was subset so that Mammoth Mountain would be centered in the image. This image is 504 x 342 pixels representing and area 10 km x 6.8 km.

In the Mammoth Mountain image, AVIRIS channels were convolved to MODIS spectral resolution to create a 20-band synthetic image. Using spectral endmembers chosen from the principal components transformation of the data, the spectral mixture algorithm was applied to the MODIS/AVIRIS synthetic image.

C. Sea Ice Mapping:

The SMA model was also used in to test its ability to perform sea ice mapping. Using a TM image of the Beaufort Sea region of the Canadian Arctic, sea ice concentrations were mapped for each image pixel. This composited image shows the pack ice in spring when melt is just beginning to occur in the snow overlying some of the sea ice. Open water is visible in the cracks between large pieces of sea ice. Some clouds are visible in the bottom of the image as well as the very top portion of the image.

IV. Results

A. Alpine snow cover Mapping Results

The atmospherically-corrected TM image subset (2500 x 2500 pixels) was used for both the spectral mixture analysis and analysis with the NDSI algorithm. In the spectral mixture analysis, three endmembers were chosen: snow, vegetation and shade. These were obtained after running a principal components transformation on the image and examining the scatterplots of the principal components to identify the purest pixels for each endmember and the total number of endmembers. After the image was unmixed into its endmember components, the scaled snow fraction was computed by dividing the snow image by the sum of the snow and vegetation images (see Figure XX). Best results appear to have been obtained for both the snow and shade fraction images with virtually all concentration values falling within the range from 0.0 to 1.0. Slightly negative values mean that there was some endmember that should have been included that wasn't. However, when additional endmembers were added, the RMS error would increase to an unacceptable level because the added endmember resulted in a greater lack of fit of the model to the data. Slightly super-positive values (greater than 1.0) mean that these pixels were more "pure" than the ones chosen for the endmembers. Changing the endmembers to these "purer" pixels resulted in a worse fit of the model to the data because those pixels were actually less representative of the endmember. The results presented here represent the best fit of the model to the data. Because of the lack of pixels containing only vegetation, this endmember is not particularly representative of "pure" vegetation. This resulted in a greater number of negative and super-positive values in this image. However, the overall RMS error with those chosen endmembers was less than 1% showing the good fit of the model to the data.

For comparison with the spectral mixture model results, the SNOMAP algorithm was applied the Glacier National Park TM image. The resulting image is shown in Figure XX.

The NDSI binary classification resulted in a total snow covered area of 3979 km^2, slightly exceeding the SMA-derived snow covered area estimate of 3820 km^2, only a 4.2% difference between the two results. Though this difference is not particularly large, it could, depending on the snow depth and spatial distribution, result in a substantially different estimate for the snowmelt/runoff from the snowpack. The snow fraction image produced using SMA is able to show the varying spatial distribution of the snowpack whereas the NDSI binary classification cannot.

Using spectral endmembers chosen from the principal components transformation of the data, the spectral mixture algorithm was applied to the 20-band MODIS/AVIRIS synthetic image and the results are shown in Figures XX-XX. The snow fraction image has values ranging from 0.0 to 1.0. This closely agrees with results from the application of the spectral mixture model to the original AVIRIS data (which have been validated using aerial photographs (Nolin, 1994). Summing the fractions of snowcover in each pixel gives the total snow covered area for the scene. From the MODIS/AVIRIS synthetic image, the total snow covered area was calculated to be 38.1 km^2 and the total from the original AVIRIS image was 37.3 km^2. Overall RMS error for the unmixed MODIS/AVIRIS scene was 1.1%. Pixels that are insufficiently illuminated have higher RMS error values as do the brightest snowcovered pixels. In general, the spectral mixture model was able to fit the data with very low error.

NDSI estimates of total snow covered area for Mammoth Mountain were significantly lower than those obtained from using the SMA method. The reason for the difference in estimates is the large number of shaded pixels evident in the image, many of which are assigned values of no snow from the SNOMAP algorithm. The NDSI method is not able to express the spatial distribution of snowcover in this rugged alpine area. SMA results from the MODIS-convolved AVIRIS image compared closely with SMA results from the original AVIRIS image.

B. Sea Ice Concentration Mapping Results

In the Beaufort Sea TM image, four endmembers were found to best characterize the spectral variability in this six-band image: sea ice, liquid water, cloud, and wet snow. Figures XX-XX show the fractional proportions of each of these endmembers with white pixels having concentrations near unity and dark pixels having the lowest concentrations. RMS error was very low for this unmixing result (~0.4%). SMA was able to map a wide range of sea ice concentrations in this image. While, currently there is no comparison with estimates of sea ice cover from an NDSI-like method, we expect to produce this comparison in the near future.

V. Conclusions

Snow cover in both the Mammoth Mountain and Glacier National Park images were mapped using the SMA method. Results from the MODIS-convolved AVIRIS image from Mammoth Mountain compared closely with SMA results from the original AVIRIS image. A comparison of SNOMAP-derived snow covered area produced value 4.2\% larger than that calculated using the SMA technique. Though this difference is not particularly large, it could, depending on the snow depth, result in a substantially different estimate for the water equivalent of the snowpack. The snow fraction image produced using SMA is able to show the varying spatial distribution of the snowpack whereas the binary classification cannot.

The SMA method appears to be effective for mapping the spatial distribution of sea ice at a sub-pixel level. Because the range of possible spectral endmembers is small in Arctic scenes this technique holds great promise for accurately characterizing the fine-scale spatial distribution of sea ice, open water, clouds, and snow.

Cryospheric components in both alpine and arctic were mapped at sub-pixel resolution using the SMA technique. However, because of the need for interactive endmember selection for each image, this technique is remains in a "pre-operational" phase. That is, until automated endmember selection can be carried out in an accurate and computationally reasonable fashion, the SMA method will not be appropriate for global operational snow and ice cover mapping. Future work on this project will focus on developing an automated endmember selection process and work-in-progress indicates that this is a promising line of research.

II. Aircraft Mission in Alaska (D. Hall, J. Foster, D. Cavalieri, C. Benson, M. Sturm and G. Linebaugh)

The overall objective of this mission was to acquire remotely-sensed measurements of snow and sea ice to permit the development of improved algorithms for mapping snow and sea ice cover, snow thickness, and sea ice concentration, using satellite data. This mission is in support of the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) and Multifrequency Imaging Microwave Radiometer (MIMR) projects. Airborne and ground-based measurements were acquired simultaneously, when possible, over many of the snow sites.

The aircraft experiment was conducted with the NASA ER-2 from Ames Research Center during the month of April 1995. 8 flights were flown - 5 snow flights and 3 sea ice flights. Passive microwave (Multichannel Imaging Radiometer (MIR)) and optical and IR sensors (MODIS Airborne Simulator (MAS)) as well as an aerial camera were on board. Satellite data from the DMSP SSMI, the NOAA AVHRR, ERS-1 and JERS-1 were also acquired.

This work was done in collaboration with the University of Alaska (Dr. Carl Benson) and the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) (Dr. Matthew Sturm), and many other scientists and students who participated in the field measurements. Results from the field and aircraft measurements will be analyzed jointly among scientists at Goddard, the University of Alaska and CRREL - Fairbanks office.

At this time, all the MIR data have been acquired and processing has begun. All flight lines are processed and are currently being registered to an EASE-GRID projection to facilitate comparisons with SSMI satellite data. The calibration of the MAS data is underway and is expected to be completed by the end of August 1995.

Flight 1 was flown on 3 April from Fairbanks, north to Prudhoe Bay, and back. Cloud cover was extensive over the Brooks Range, but very clear over the rest of the flight line, including over a 150-km flight path over the Arctic Ocean (Beaufort Sea). On 4 April, a snow pit was dug on top of Ester Dome (elev. 2,364 ft.). Snow depth was 1 m. Snow crystals were taken at 10-cm intervals and preserved via cryogenic techniques for study by USDA personnel utilizing an electron microscope. Flight 2 was flown on 5 April, over the established Fairbanks grid at local noon. There was less than 10 percent cloud cover. Ice measurements were made on Harding Lake along with sun photometer measurements. Flight 3 was flown on 6 April, over the Fairbanks grid again, but 2 hours earlier than Flight 2. There was less than 10 percent cloud cover again. Flight 4 was flown on 7 April over the Bering Sea with about 50 percent cloud cover. The Ester Dome snow pit was revisited on 10 April. Depth remained constant at 1 m. Flight 5 occurred on 13 April, again over the Fairbanks grid at local noon, with 10-15 percent cloud cover. Sun photometer measurements were again made during the 3-hour flight. Flight 6 was on 21 April, again over the Fairbanks grid, but at a very low Sun angle (7:00 A.M. takeoff), with 50-70 percent cloud cover. Flight 7 was flown on 23 April over the Barrow area with almost complete cloud cover, and flight 8 was flown on 24 April over the Bering Sea, again, with almost complete cloud cover.

III. September MODIS Snow/Ice Workshop (D. Hall, B. Conboy)

Plans have been formulated for a workshop to be held at the U.S. Geological Survey and at Goddard on September 13-14, 1995. The objective of the workshop is for a representative group of the snow and ice community to review the snow and ice algorithms and to comment on the utility of the algorithms and also to discuss needs for post-launch MODIS snow and ice algorithms.

The following individuals have agreed to attend. Those attendees with an asterisk after their name will be giving a presentation.

Steven Ackerman/University of Wisconsin
Richard Armstrong/University of Colorado
Roger Barry/University of Colorado
Michael Baumgartner*/University of Bern, Switzerland
Cheryl Bertoia*/NOAA/Navy Joint Ice Center
Tom Carroll*/NOAA/NOHRSC
Don Cavalieri/NASA/GSFC
Joey Comiso*/NASA/GSFC
Bert Davis/U.S. Army CRREL

Jeff Dozier/University of California at Santa Barbara
Jim Foster/NASA/GSFC
Barry Goodison/Department of Environment, Canada
Robert Green*/NASA/JPL
Dorothy Hall*/NASA/GSFC
Bryan Isacks/Cornell University
Jeff Key*/University of Colorado
Mike Manore/CCRS, Canada
Anne Nolin*/University of Colorado
Claire Parkinson/NASA/GSFC
Bruce Ramsay*/NOAA/NESDIS
Al Rango/USDA
George Riggs*/NASA/GSFC/RDC
Dave Robinson*/Rutgers University
Walter Rosenthal/University of California at Santa Barbara
Drew Rothrock/University of Washington
Vince Salomonson/NASA/GSFC
Greg Scharfen*/University of Colorado
Larry Smith/Cornell University
Konrad Steffen*/University of Colorado
Anne Walker/Department of Environment, Canada
Ron Welch*/South Dakota School of Mines and Technology

The preliminary agenda of the workshop follows:

FIRST MODIS SNOW AND ICE WORKSHOP

Preliminary Agenda

Wednesday, September 13, 1995

7:45 - 8:45 A.M. Scenic bus ride from Greenbelt, Maryland to Reston, Virginia, featuring morning rush hour on the Beltway

Combined ACSYS/MODIS Session on Snow

U.S.G.S. Auditorium, Reston, VA

8:45 - 9:00 Refreshments

9:00 - 9:15 R.G. Barry and D. K. Hall - Welcome to combined ACSYS/MODIS

workshop

9:15 - 9:45 T. Carroll - Remote sensing of snow in the cold regions

9:45 - 10:15 D.K. Hall - Satellite snow-cover mapping

10:15 - 10:30 B. Ramsay - Interactive multisensor snow and ice mapping system

10:30 - 10:45 Break

10:45 - 11:00 D. Robinson - An analysis of the NOAA satellite-derived snow-cover record, 1966 - present

11:15 - 11:30 M. Baumgartner - An integrated analysis system for monitoring snow cover variations in the Alps using NOAA/AVHRR data

11:30 - 12:00 C. Bertoia - Use of satellite data for operational sea ice and lake ice studies

12:00 - 12:30 Discussion

12:30 - 1:30 Lunch

1:30 - 3:00 MODIS Session on snow cover mapping

Conference room at U.S. Geological Survey (to be announced)

1:30 - 2:00 G. Riggs - MODIS snow and ice algorithm development

2:00 - 2:15 A. Nolin - Fractional snow-covered area mapping using spectral mixture analysis

2:15 - 2:30 J. Key - The cloud and surface parameters retrieval (CASPR) system for polar AVHRR

1:30 - 2:45 R. Green - Snow distribution, grain size and melting properties remotely measured and validated in the solar reflected spectrum

2:45 - 3:00 Break

3:00 - 5:00 Mapping Sea Ice and clouds with Optical Sensors

3:00 - 3:15 R. Welch - Polar cloud and surface classification using Landsat data

3:15 - 3:30 K. Steffen - Potential MODIS applications for ice surface studies based on AVHRR experience

3:30 - 3:45 J. Comiso - Cloud masking and surface temperature distribution in the polar regions using AVHRR and other satellite data

3:45 - 4:00 Break

4:00 - 4:15 Another sea ice presentation

3:45 - 4:50 Discussion of snow and sea ice algorithm development

5:00 - ? Bus leaves for Greenbelt featuring afternoon rush hour on the Beltway.

Thursday, September 14, 1995

Goddard Space Flight Center, Greenbelt, Maryland
Building 22, Room 365

8:30 - 8:45 D. Hall - Day 2 opening comments

8:45 - 9:00 G. Scharfen - MODIS activities at the NSIDC DAAC

9:00 - 9:15 Form working groups in various conference rooms

Groups:

I. MODIS snow at-launch products - R. Davis, Chair

II. MODIS ice at launch products - C. Bertoia, Chair

III. Future MODIS ice products (post-launch) - R. Welch, Chair

IV. Utility of MODIS snow and ice products - A. Walker, Chair

9:30 - 12:00 Discuss MODIS snow and ice algorithms and provide written comments

12:00 - 1:00 Lunch

1:00 - 2:00 Finish writing comments for workshop proceedings

2:00 - 3:30 Oral reports from working group chairs, and disucssion

2:00 - 2:20 Group I

2:20 - 2:40 Group II

2:40 - 3:00 Group III

3:00 - 3:20   Group IV

3:20 -   3:30 D. Hall - Closing remarks including a discussion of a need for a future versions of the algorithms have been delivered to SDST. Product description documents, the ICD and the HDF File Specification Document for the algorithm data products were generated.

Improvements to the algorithms have been made based on testing and analysis of the algorithms with TM data. The sea ice algorithm has been run on many TM scenes. The algorithm has successfully identified sea ice, open water, and discriminated most cloud types from sea ice. Cirrus clouds are not consistently separated from sea ice. Collaboration with Dr. Ron Welch of the South Dakota School of Mines and Technology has been fruitful. We have undertaken a comparison of results of Dr. Welchís technique of classification of TM imagery of polar regions with our techniques for identifying sea ice and snow-covered land areas.